Catena 160 (2018) 345–353

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Rational land-use types in the karst regions of China: Insights from soil organic matter composition and stability

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ARTICLE INFO

Keywords:
^{13}C NMR
Humic acid
Soil organic carbon
Functional groups
Soil nutrient

ABSTRACT

Composition and stability of soil organic matter (SOM) affect the sustenance and productivity of soil over the long-term. This issue is particularly important for karst regions in China where the water supply and fertilizer use are limiting factors. Here, we used four indicators to evaluate changes in the composition and stability of SOM quantitatively in five main land-use types in karst area, including primary forest [PF], 15-year secondary forest [SF], grazing secondary forest [GF], abandoned farmland [AF] and farmland [FL]. We collected soil samples at a depth of 0–20 cm to conduct the analyses. Four indicators were used: soil physical and chemical properties, active organic carbon (C), humus C composition, and SOM functional groups. Our results showed that the content of SOM, total nitrogen, and easily oxidized organic C at 0–20 cm soil depth differed among the five land-use types ($P < 0.05$). For humic acid C concentration, the land-use types were ordered as: SF > PF > GF > FL > AF. Solid-state ^{13}C NMR spectra showed that the highest ratio of Alkyl C/O-alkyl C was in AF, while the lowest was in SF. Overall, the comprehensive quality of SOM in different land-use types was PF (setting 100%) > SF (83.1%) > GF (58%) > AF (30.9%) > FL (29.9%). For karst areas, we suggest that farmlands in sloping area should be converted back to forests, with only moderate grazing being permitted, whereas farmlands in the plains should implement grain-forage rotation and grain-soybean rotation to meet the needs of the growing population and economic development. In conclusion, our findings provide a scientific basis from which to delineate rational land-use types for different land (geographical and geological) formations.

1. Introduction

Guizhou Province in China is one of three karst areas in the world. The socio-economic level of this province is low, due to high population pressure and serious eco-environmental situation (Guo et al., 2013). Limestone areas, or "karst", are specific geographical areas with extensive bare rocks, making it difficult to conserve soil and water (Gams, 1993). In these regions, the soil profile is shallow and porous, with the process of soil formation being slow compared to Guangxi (Wang et al., 1999; Yuan and Cai, 1988). Major soil erosion, with a poor ability to conserve water and fertilizers, results in low vegetation productivity (Pimentel et al., 1995). These phenomena are worsened by the unique terrain features of this region, such as steep and rugged slopes (Fig. 1). Consequently, ecological systems in karst areas are very sensitive to changes in land-use (Wang et al., 2014).

Different land-use types, such as forests, grazing, and farmland, have different impacts on soil fertility and productivity. Long et al. (2006) reported that agroforestry had good fertility performance, followed by the focused management of irrigated farmland, and extensive management of dry slope farmland. Yang et al. (2013) found that soil quality, porosity, and capillary water holding capacity were the best in artificial grasslands, followed by natural grasslands and farmland. Disturbance caused by human activities, such as land reclamation, fire, and logging, are the important factors contributing to soil degradation interfered soil, topography, and other factors (Jiang et al., 2009; Li et al., 2009; Zhang et al., 2010). However, it is difficult to restore such ecosystems in karst areas, because the process of soil formation is slow (Liu et al., 2005; Liao et al., 2012; Di et al., 2015). In Guizhou Province, farmers have largely cultivated farmlands on slopes to meet population

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http://dx.doi.org/10.1016/j.catena.2017.09.029
Received 4 April 2017; Received in revised form 23 September 2017; Accepted 27 September 2017
Available online 11 October 2017
0341-8162/

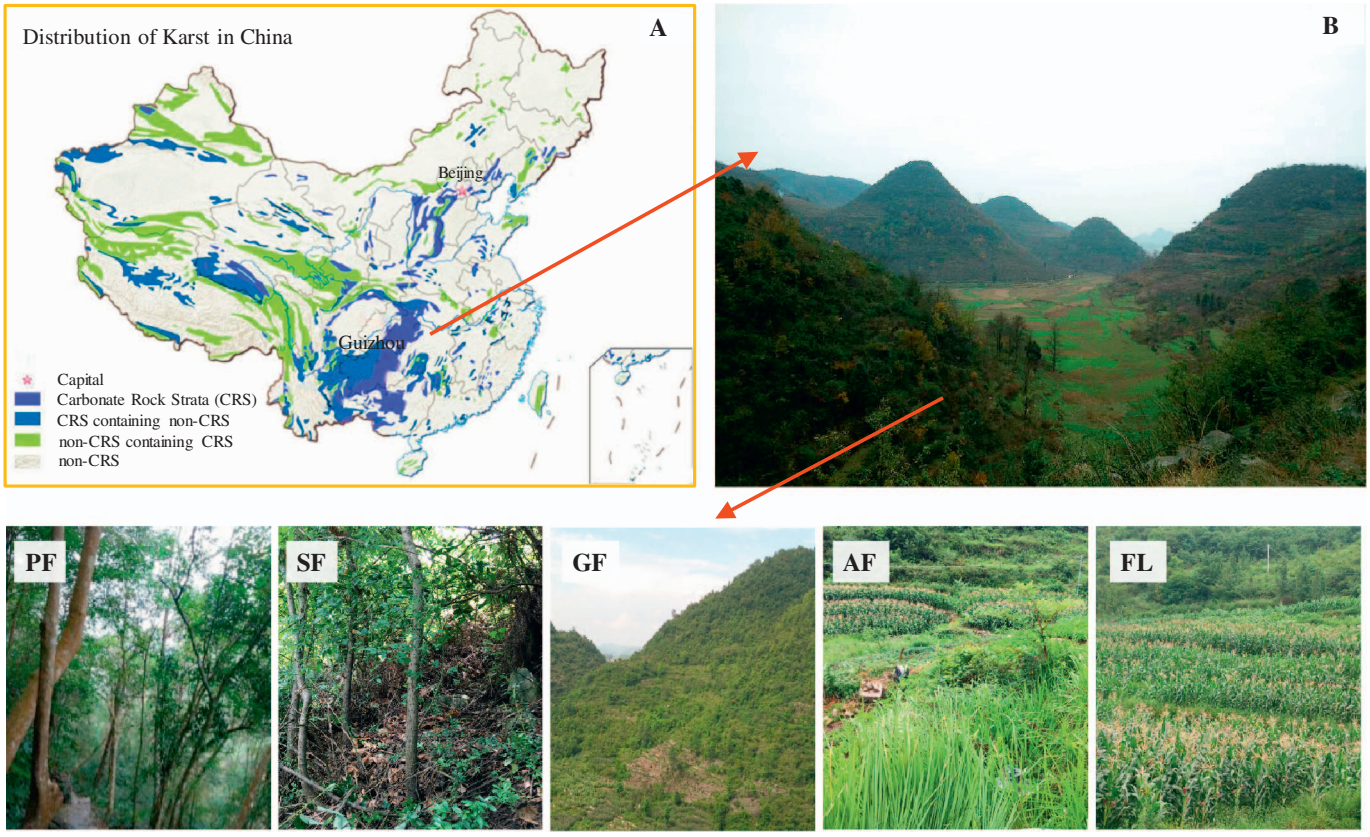

Fig. 1. Spatial distribution of karst area in China and the main land-use types in Guizhou Province. Primary forest, PF; secondary forest, SF; grazing on secondary forest, GF; abandoned farmland, AF; farmland, FL.

demand. For instance, today, croplands with slopes of > 25° account for > 20% of the arable land in the province (Chen et al., 2014), resulting in major soil erosion (Wei et al., 2016). Therefore, it is important to implement rational land-use to sustain high productivity, as well as to conserve water and fertilizer use, in the long-term.

The soil supports plant growth by supplying essential nutrients, water and air; thus, in the long run, the content and structure of soil organic matter (SOM) influences, and even controls, the productivity of vegetation, to a large extent (Lal, 2004). Humus is the important part of SOM and is primarily formed from the complex organic matter in animal and plant residues, such as lignin, cellulose, and tannin. It is the main cementing agent of soil aggregates in the formation of water stable agglomeration structures. Humus can change soil porosity and the water gas ratio, and it also improves soil tightness. Overall, higher humus content favors the formation of good soil structure (Bronick and Lal, 2005). Thus, the productivity of areas subject to major soil erosion might be negatively impacted. This is the case in the karst region of Guizhou Province in China, where the terrain is steep and mountainous, with abundant rock pores and rainfall (mean annual precipitation about 1360 mm). Therefore, it is necessary to enhance the content and stability of SOM to reduce erosion, improve soil structure, and improve the long-term supply ability of soil. In Huanjiang County of northwest Guangxi, Tang et al. (2014) demonstrated that the 8-year conversion of cropland to forest significantly increased soil organic carbon (SOC) by 24%, along with a significant increase in soil water-soluble organic carbon (WSOC), particulate organic carbon (POC), and easily oxidized organic carbon (EOC). Furthermore, in the karst area of Guangxi Province in Huanjiang County, Liu et al. (2015) found that SOM content was much higher in primary forests compared to grasslands, which was largely due to the influence of the physical and chemical properties of the soil. Thus, a systematic and comprehensive assessment of different land-use types is required on SOM composition and stability in the karst region of Guizhou Province in China. However, first, it is necessary to determine how different land-use types affect SOM composition and stability to provide rational suggestions for land-use types in this region.

In this study, we aimed to quantify changes in the composition and stability of SOM in the karst area of Guizhou Province. Specifically, we selected five main land-use types (Primary forest [PF], 15-year Secondary forest [SF], Grazing secondary forest [GF], Abandoned farmland [AF], and Farmland [FL]), and we used four types of indicators for SOM (soil physical and chemical properties, active organic C, humus C compositions, and SOM functional groups on basis of ^{13}C NMR technology). The main objectives of this study were to: 1) systematically determine how different land-use types influence the content and composition of SOM using different indicators; and 2) comprehensively and quantitatively evaluate how different land-use types impact soil quality. Our findings are expected to help managers to determine rational land-use types for karst regions in China, which could be applied to enhance the sustainable development of fragile karst ecosystems in other areas globally.

2. Materials and methods

2.1. Soil sampling

The karst area in China is mainly distributed along the Yunnan-Guizhou Plateau (Fig. 1 A). In this study, field experiment plots were established in a small catchment of Chenqi, and were administrated by Puding Karst Ecosystem Research Station, Chinese Academy of Sciences (E 105° 45′ 41.7″–105° 46′ 33.6″, N 26° 14′ 49″–26° 16′ 5.49″). The study area is a typical plateau, with a humid subtropical monsoon climate. The mean annual precipitation (MAP) is 1360 mm and the mean annual temperature (MAT) is 14 °C.